

# A Dynamically Polarized Hydrogen and Deuterium Target at Jefferson Lab\*

J. R. Boyce, C. Keith, J. Mitchell, M. Seely

*Thomas Jefferson National Accelerator Facility, Newport, News, VA, 23606*

S. Bültmann, D. G. Crabb, & C. Harris

*University of Virginia, Charlottesville, VA, 22901*



Polarized electron beams have been successfully used at Jefferson Lab for over a year. We now report the successful achievement of polarized targets for nuclear and particle physics experiments using the dynamic nuclear polarization (DNP) technique. The technique involves initial irradiation of frozen ammonia crystals ( $\text{NH}_3$  and  $\text{ND}_3$ ), using the electron beam from the new Free Electron Laser (FEL) facility at Jefferson Lab, and transferring the crystals to a special target holder for use in Experimental Halls. By subjecting the still ionized and frozen ammonia crystals to a strong magnetic field and suitably tuned RF, the high electron polarization is transmitted to the nucleus thus achieving target polarization. Details of the irradiation facility, the target holder, irradiation times, ionized crystal shelf life, and achieved polarization are discussed.

## INTRODUCTION

New information associated with the nucleus can be obtained from experiments with both a polarized beam and a polarized target. Polarized electron beams have been successfully used at Jefferson Lab for over a year. Target nuclei polarization at Jefferson Lab, however, has only recently been attempted using Dynamic Nuclear Polarization, or DNP (1).

The basic idea behind DNP consists of using properly tuned microwaves in a high magnetic field to transfer the polarization of atomic electrons to the nuclei. Solid ammonia, in the form of  $\text{NH}_3$  and  $\text{ND}_3$  crystals is a good target material since it is hydrogen- or deuterium-rich and can be readily paramagnetically doped with an unpaired or quasi-free electron. Since the relaxation time of the electron spins is short (on the order of milli-seconds) and that of the nucleons is long (on the order of minutes), a relatively small number of unpaired electronic spins are required to polarize a large number of nuclear spins.

Some of the paramagnetic centers created through irradiation are stably trapped in the ammonia crystals at temperatures as high as 77 K. In effect, the "self life" of these irradiated crystals can be several months if they are stored in liquid nitrogen. SLAC experiments E143 (2-5) and E155 have demonstrated

the viability of DNP achieving polarization of up to 85% for protons and 38% for deuterons.

Here we describe our initial efforts to produce such polarized hydrogen and deuterium targets for the nuclear physics research program at Jefferson Lab. We describe the FEL Irradiation Facility, two irradiation procedures: "warm" and "cold," and initial results.

## THE FEL IRRADIATION FACILITY

The layout of the FEL accelerator is shown in Figure 1. The space between the beam dump and the wiggler is the irradiation location. For these irradiations, the electron beam from the injector was accelerated to 36 MeV by the cryomodule and directed into the straight-ahead beam dump through the irradiation set-up. The wiggler was not used.

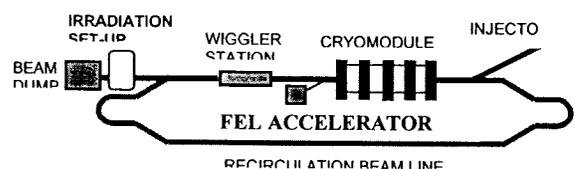


Figure 1. The Jefferson Lab FEL Accelerator layout.

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The layout of the first irradiation set-up - the "warm" set-up - where the ammonia crystals were in a bath of liquid argon at 87.3 K, is shown in Figure 2. A dewar, modified to have two thin window ports for beam entrance and exit was placed between the beam-line exit and beam dump.

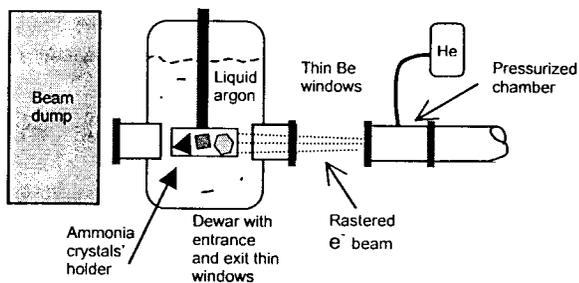


Figure 2. The "Warm" irradiation set-up.

Of major concern when the electron beam is brought out of the normal high vacuum system is the possibility of a breach of the vacuum system due to beam burn through, thus letting room air reach the srf accelerator. To mitigate this situation, a chamber pressurized to 1 atm of helium was placed at the beam exit location. Pressure in the chamber is monitored and interlocked to gate valves that will actuate on a pressure drop. Thus, only a small amount of helium, not room air, would reach the SRF accelerator with vacuum system breach.

A second safeguard against beam burn-through is a raster pattern placed on the beam by air core magnets upstream from the beam's exit chamber. The raster prevents local hot spots from occurring due to the beam and ensures uniform irradiation of the ammonia crystals.

For the "warm" irradiation targets, a total dose of  $\sim 10^{17}$  electrons/cm<sup>2</sup> was needed rastered over 4.8 cm<sup>2</sup>. This translated into about an 11 hour run with a beam current of 2  $\mu$ A. Two "warm" irradiations were done: one for crystals of NH<sub>3</sub> and one for crystals of ND<sub>3</sub>.

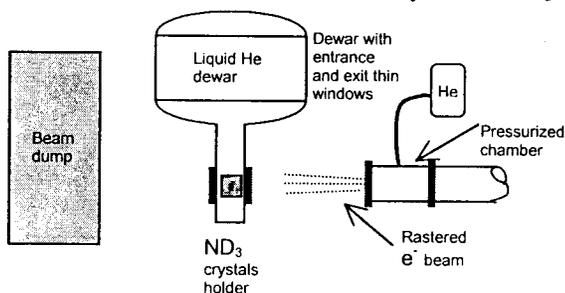


Figure 3. The "Cold" irradiation set-up.

The "cold" irradiation was at liquid helium temperatures ( $\sim 4$  K). The "cold" dewar was also modified for minimum beam loss in the dewar and maximum crystal irradiation. Figure 3 is a sketch of the cold set-up. Only ND<sub>3</sub> was used in the "cold" irradiation.

Experience has shown that "warm" irradiation of ND<sub>3</sub> is insufficient for achieving optimal polarization. Previously, "warm" irradiation have been supplemented by additional "in situ" irradiations at 4 K to achieve the desired polarization. We have attempted to get the same results with a liquid helium temperature, or "cold," irradiation at the FEL. This required a dose of one quarter that of the "warm" irradiation. The beam current was reduced to minimize the heat loss, and thus helium boil-off, during the run. The run time for a 1  $\mu$ A average beam was estimated to be about 5 hours.

The basic run time procedure was to perform three irradiations:

- a "Warm" irradiation of one sample of NH<sub>3</sub>,
- a "Warm" irradiation of one sample of ND<sub>3</sub>, and
- a "Cold" irradiation of one sample of ND<sub>3</sub>.

Seven days of run time were allocated for this irradiation effort: Two for setup and take-down, two for warm runs, one for changing from warm to cold configuration, and two for the cold runs.

## RESULTS AND DISCUSSION

In actuality, the entire procedure was successfully executed in four days during a stability test of the FEL facility electron beam. The beam was found to be very stable, delivering the requested beam current without anticipated interruptions.

Other laboratories have been successful in storing irradiated crystals for several months without significant loss of ferromagnetic centers and thus without significant deterioration in polarizability of the target material. Typically polarizations of 90% have been obtained for NH<sub>3</sub> and about 35-40% for ND<sub>3</sub>. For the Jefferson Lab irradiated samples, polarization of >90% has been achieved in the NH<sub>3</sub> samples. The Jefferson Lab irradiated ND<sub>3</sub> have been kept in cryogenic storage until the supply of SLAC irradiated samples is fully utilized. It is expected that the ND<sub>3</sub> polarization will be roughly the same as for the SLAC samples, or  $\sim 38\%$ .

## CONCLUSIONS

Target polarizations can be achieved using the technique of DNP and Jefferson Lab has started a program to utilize this technique to supply polarizable targets for experiments in the nuclear physics research program. This was accomplished during accelerator stability tests of the newly constructed FEL facility.

Proton polarizations of >90% were achieved. Deuteron polarizations have not been verified as of this date but are expected to be on the order of previous attempts by other laboratories:  $\sim 38\%$ .

This achievement also illustrates the inter-relationship between basic research and applications

research, namely: technology improvements in one field many times benefit the other field.

### ACKNOWLEDGMENTS

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